BROCKWAY SUMMIT TEST PLOTS SITE REPORT

May 2008

INTRODUCTION

This report describes monitoring data and results from the Brockway test plots, which were constructed in 2005. The Brockway test plots are located on Highway 267, just north of the north shore of Lake Tahoe (Figure 1). This cut slope site was originally treated in 1998 as part of a Caltrans erosion control project. Portions of this slope and the surrounding slopes have received follow-up treatment. The effects of the following treatments on erosion control capacity were investigated: tilling depth, amendment type (compost versus tub grindings), seed rate, and Biosol fertilizer rate. Infiltration rate, sediment yield, soil density, and plant cover were some of the measurements used to study the erosion control capacity (Figure 2).

Figure 1. Site location of Brockway test plots.

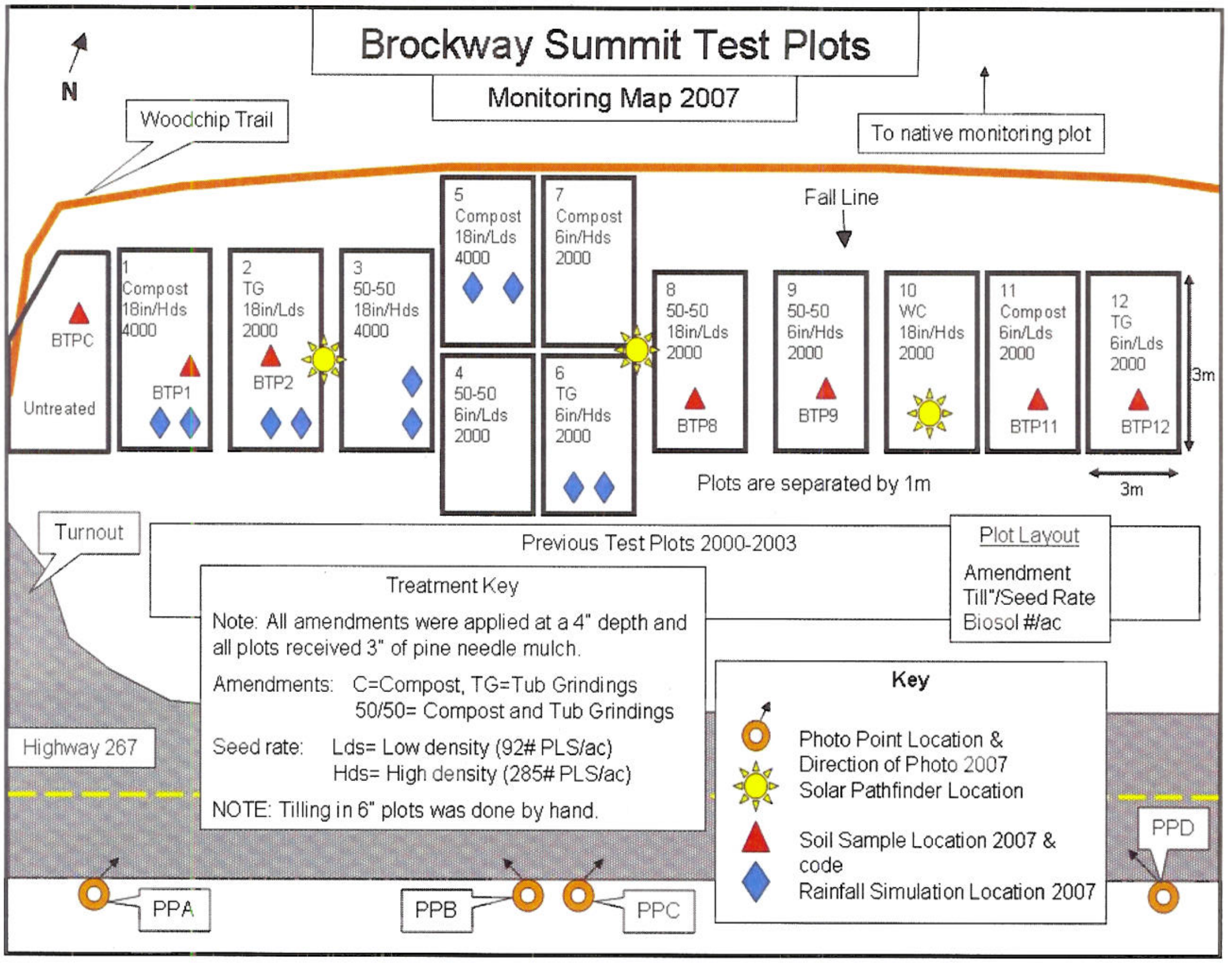

Figure 2. Layout and 2007 monitoring locations of Brockway test plots.

PURPOSE

This site was monitored to investigate:

1) The effect of hand tilling to 6 inches (15 cm) versus machine tilling to 18 inches (46 cm) on infiltration, sediment yield, soil density, plant establishment, and long term plant survival.
2) The effect of different organic materials incorporated into the soil (tub grindings or compost) on infiltration, sediment yield, soil density, supporting plant growth, and establishing necessary soil nutrients.
3) The effect of different fertilizer (Biosol) rates on soil nutrient status and plant growth.
4) The effect of different seed rates on plant establishment and growth.

SITE DESCRIPTION

This site is located at an elevation of 6,900 feet (2,125 m) above mean sea level (AMSL), and is west to southwest facing. The average slope at the Brockway test plot site is 28 degrees. The soil is shallow, highly consolidated and is derived from volcanic parent material. Surrounding soils are classified as Umpa, Jabu, Tahoma, and Fugawee, though the existing substrate shows little resemblance to mature surrounding soils. In 2007, soil particle analysis classified the soils at Brockway summit as sandy loams with 72% sand, 12-16% slit and 11-15% clay sized particles.

Surrounding vegetation consists of a mixed conifer shrub community. Dominant trees consist of white fir (Abies concolor), Jeffrey pine (Pinus jefferyi), incense cedar (Calocedrus decurrens) and sugar pine (Pinus lambertiana). Shrubs consist of green leaf manzanita (Arctostaphylos patula), Ceanothus species, huckleberry oak (Quercus vaccinifolia), and bitter cherry (Prunus emarginata).

METHODS & MATERIALS

Treatments

1998 Treatments

The test plots site was originally cut and graded for the installation of Highway 267. In 1998, it was laid back to reduce the over-steepened slope angle, and received a surface treatment. Compost was spread to a depth of ¼ inch (0.63 cm) across the surface. Organic fertilizer (Biosol) and seed were raked into the compost layer. Finally, a ½ inch (1.27 cm) layer of pine needle mulch was applied. An area that currently consists of this treatment was used as a control plot in this study.

2005 Test Plot Treatments

In 2005, 12 test plots were constructed in an area that had received treatment in 1998. One plot was disturbed during construction and left untreated. Each plot is 10 feet by 10 feet (3 m by 3 m) with a buffer of 3.3 feet (1 m) between plots (Figure 2). Treatment information is presented in Table 1. Each test plot received a variation of full erosion control treatment, referred to in this report as full treatment. Full treatment includes tilling organic matter into the soil, fertilizer, native seed, and mulch application.

Table 1. Brockway Test Plots treatments. The 'no treatment' (control) plot (not included in the table) was located to the west of Plot 1.

Plot	Tilling Depth (in)	Tilling Method	Biosol (kg)	Compost (in)	Tub grindings (in)	50/50 Compost + Tub grindings (in)	Seed rate (lbs/acre)	Pine Needle Mulch (in)
1	18	Backhoe	4000	4			285	3
2	18	Backhoe	2000		4		92	3
3	18	Backhoe	4000			4	285	3
4	6	Hand Till	2000			4	92	3
5	18	Backhoe	4000	4			92	3
6	6	Hand Till	2000		4		285	3
7	6	Hand Till	2000	4			285	3
8	18	Backhoe	2000			4	92	3
9	6	Hand Till	2000			4	285	3
10	18	Backhoe	2000		4		285	3
11	6	Hand Till	2000	4			92	3
12	6	Hand Till	2000		4		92	3

Amendments

Compost, tub grindings, or a fifty-fifty mix of compost and tub grindings was spread evenly across the entire surface of each plot to a depth of 4 inches (10 cm). Compost was obtained from Full Circle Compost. The "Integrated Tahoe Blend 25%" of compost was applied and was composed of 25% fine material passed through a 3/8 inch (0.95 cm) diameter screen and 75% coarse woody material ranging in diameter from 3/8 inch to 3 inches (7.6 cm). The "Integrated Tahoe Blend" compost spread to a depth of 4 inches provided approximately 2,500 lbs/acre (2,800 kg/ha) nitrogen equivalent. Type 1 tub grindings obtained from the local landfill site are composed of raw trees; not processed construction wood. These tub grindings often include root material and attached soil, creating a material with a greater potential nutrient level than normal tub grindings. The tub grindings provided approximately 190 lbs/acre (210 kg/ha) nitrogen equivalent when spread at a depth of 4 inches. The mixture with 50% tub grindings and 50% compost provided approximately 1,350 lbs/acre (1,520 kg/ha) of nitrogen equivalent.

Tilling

Test plots were either tilled by hand to a depth of 6 inches (15 cm) or tilled using a mini-excavator to a depth of 18 inches (46 cm), incorporating the tub grindings and/or compost into the soil (Figure 3 and Figure 4).

Figure 3. Tilling by mini excavator to 18 inches.

Figure 4. Hand tilling to 6 inches.

Fertilizer, Seed, and Mulch

Biosol, a slow release fertilizer, was then applied and raked into the soil at a rate of either 1,784 lbs/acre (2,000 kg/ha) or 3,568 lbs/acre (4,000 kg/ha) (Table 1 and Figure 2). After Biosol incorporation, native perennial grasses and forbs were raked into the soil at a rate of either 285 lbs/acre (320 kg/ha) or 92 lbs/acre (103 kg/ha) at each plot (Table 2). Finally, a 3 inch (7.6 cm) layer of native pine needle mulch was spread on all the plots by hand.

Table 2. Pounds of live seed by species (PLS).

Seed Mix Species	PLS (lbs)
Achnatherum occidentalis (Western needlegrass)*	3.57 (30% pls)
Lotus purshianus (Spanish Clover)	1.65
Lupinus fulcratus (lupine – inoc)	1.1
Lupinus argentus (silverleaf lupine)	1.1
Achillea millefolium (white yarrow)	1.1
Bromus carinatus (mountain brome)	5.5
Deschampsia elongata (slender hairgrass)	1.1
Erigonum nudum (naked buckwheat)	1.1
Purshia tridentata (antelope bitterbrush)	1.1
Elymus glaucus (Stanislaus 5000 blue rye)	5.5
Total pounds live seed	19.25
*Western needlegrass may not have been available at the time of treatment.	

Monitoring Methods

Cover

Cover point monitoring is a statistically defensible method of measuring plant and foliar cover (hereafter referred to as either "plant cover" or "foliar plant cover"), plant composition and mulch cover. Cover data is used in combination with rainfall simulation data to establish whether there is a relationship between sediment yield and cover.

The Brockway test plots were monitored in July of 2006. Cover was measured using the cover point method along randomly located transects.[1] The cover pointer consists of a metal rod with a laser pointer mounted 3.3 ft (1 m) above the ground. After the rod was leveled, the button on laser pointer was depressed and two cover measurements were recorded (Figure 5 and Figure 6):

1) the first hit cover, which represents the first object intercepted starting from a height of 3.3 ft (1 m) above the ground
2) the ground cover hit (second hit), which is the low-lying vegetation or soil below the first hit cover, at the ground levelf

The first hit cover measures the foliar cover by plants (leaves and stems). It does not measure the part of the plant actually rooted in the ground. The first hit vegetation is then moved aside and a ground cover hit (second hit) measures the presence of litter/mulch, basal (or rooted) plant cover, rock and woody debris and/or bare ground. Total ground cover represents any cover other than bare ground.

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[1] Hogan, Michael. Luther Pass Monitoring Report: Plant and Soil Cover Monitoring for Evaluating Sediment Source Control Success in the Lake Tahoe Basin. 2003. South Lake Tahoe, CA, Lahontan Regional Water Quality Control Board.

Figure 5. Cover point montoring is data collected along transects.

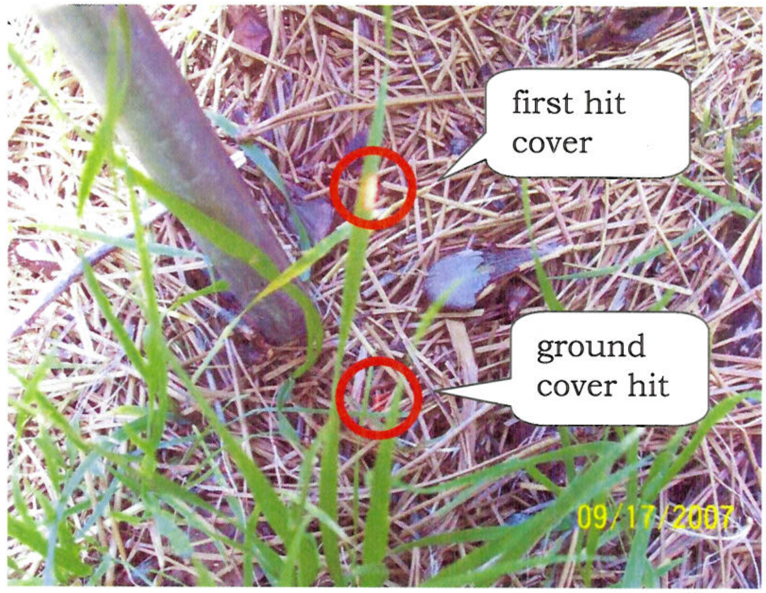

Figure 6. Cover point monitoring rod with first hit and ground cover hit by the laser pointer. The laser pointer hits are circled in red. The first cover hit is a native grass and the ground cover hit is pine needle mulch.

Plant cover, both ground and foliar, was recorded by species and then organized into cover groups based on four categories: lifeform (herbaceous/woody), perennial/annual, native/alien (2007 only), and seeded/volunteer (2007 only). Perennial herbaceous species includes seeded grasses, native grasses and forbs, and any non-native perennial species. Annual herbaceous species include native annuals such as knotweed (Polygonum sp.) and invasive species such as cheatgrass (Bromus tectorum). Woody species are any native or introduced tree and shrub species of interest. Each species was then classified based on whether it was native to the Tahoe area, and whether it was seeded during treatment.

Data is also presented on the percentage of cover by species. Species of interest are species that were seeded and problem species such as cheatgrass. An ocular estimate of cover at each plot was also recorded and includes many species not detected in the cover point sampling (Appendix A).

Soil and Site Physical Conditions

Soil Density

Soil density and soil moisture were measured along the same transects as the point cover data for all test plots, the control plot, and a nearby native area. Cone penetrometer measurements were used as an index for soil density. A cone penetrometer with a ½ inch diameter tip was pushed straight down into the soil until a maximum pressure of 350 pounds per square inch (psi) (2,411 kPa) was reached. The depth, in inches, at that pressure was recorded as the depth to refusal (DTR) (Figure 7 and Figure 8). A denser soil is less likely to allow infiltration. Rainfall simulations conducted on roadcuts in Oregon found increased infiltration rates in soils with penetrometer depths to refusal (DTRs) greater than 4 inches (10 cm).[2]

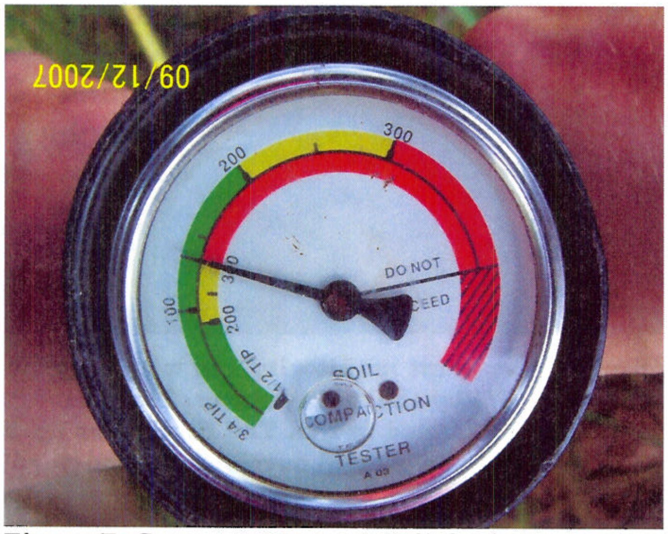

Figure 7. Cone penetrometer dial, showing pressure applied in pounds per square inch.

Figure 8. Conducting cone penetrometer readings along transects.

Soil Moisture

A hydrometer was used to measure volumetric soil moisture content adjacent to the penetrometer readings at a depth of 4.7 inches (12 cm) (Figure 9). Three solar radiation measurements were collected with a Solar Pathfinder throughout the Brockway test plots and at the native area (Figure 10). Solar input affects evaporation rates and soil temperature, which may affect time of seed germination, germination rate, rate of plant growth, and soil microbial activity. Therefore, it is an important variable to consider when monitoring plant growth and soil development.

[2] Grismer, M. Simulated Rainfall Evaluation at SunRiver and Mt Bachelor Highways, Oregon. Unpublished.

Figure 9. Conducting soil moisture readings along transects.

Figure 10. Solar Pathfinder in use.

Figure 11. Testing soil shear strength.

Soil Strength

In 2007, soil strength measurements were collected along the same transects and cover, soil density, and soil moisture (Figure 11). A hand-held shear vane with 1.5 inch (3.8 cm) long blades was pushed into the soil to a depth of 3 inches (7.6 cm). The shear vane was then turned until the soil could no longer resist the force exerted by the blades and the soil structure either deformed or fractured. This force was then recorded as the "shear stress" in kilopascals (kPa). Forty kilopascals was the maximum force the shear vane could measure. Shear stress values greater than 40 kPa were recorded as 40 kPa.

Soil strength can be an important indication of a soils resistance to mass slope failure under high moisture conditions. The shear vane method of determining shear strength has been regularly used in agricultural soils and various laboratory tests[3], but has not been applied to many forest soils. Large amounts of rocks, coarse organic material (wood, roots and large tub grindings) may affect soil shear strength measurements. In addition, the density of plant roots has been shown to increase soil strength in laboratory tests.[4]

Solar Exposure

In 2006, solar radiation measurements were taken at three locations within the test plots area and at three locations at the native site. These measurements were taken using a Solar Pathfinder (Figure 10). Solar input affects evaporation rates and soil temperature, which may affect time of seed germination, germination rate, rate of plant growth and soil microbial activity. Therefore, it is an important variable to consider when monitoring plant growth and soil development.

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[3] Tengbeh, G.T. 1993. The Effect of Grass Roots on Shear Strength Variations with Moisture Content. *Soil Technology*. Vol. 6. pp. 287-295.

[4] Ibid. pp. 287-295.

Soil Nutrient Analysis

Soil samples were collected from the untreated plot and plots 1, 2, 3, as well as the native site in 2006 (Figure 2). In 2007, samples were taken from 1, 2, 8, 9, and 11 (Table 1 and Figure 2). Three soil sub-samples at each plot were collected from the mineral soil beneath the mulch layer to a depth of 12 inches (30 cm) (Figure 12). These sub-samples were combined and sieved to remove any material larger than 0.08 inches (0.2 cm) in diameter. Samples were sent to A&L Laboratories (Modesto, CA) to be analyzed for S3C (a suite of nutrients), total Kjeldahl nitrogen (TKN), and organic matter. A control sample and a treatment sample were analyzed for particle size distribution.

Figure 12. Soil sub-sample collection.

Rainfall Simulation

In 2006, rainfall simulation was conducted at the untreated plot and test plots 1, 2, and 3. In 2007, rainfall simulation was conducted on test plots 1, 2, 3, 5, and 6 (Figure 2). Different rainfall rates were applied to different plots depending on their propensity to runoff. The rainfall rates were either 3.8 or 4.7 inches/hour (9.6 or 12 cm/hour). All rainfall rates are greater than the rate of the 20 year, 1 hour "design storm" for the local area.

The rainfall simulator "rains" on a square plot from a height of 3.3 feet (1 meter) (Figure 13 and Figure 14). The rate of rainfall is controlled, and runoff is collected from a trough at the bottom of a 0.6 square meter (6.5 ft^2) frame that is pounded into the ground. The volume of water collected is measured; and the volume of infiltration is calculated by subtracting the volume of runoff from the total volume of water applied to the plot. If runoff was not observed during the first 30 minutes, the simulation was stopped. The average steady state infiltration rate was calculated and will hereafter be referred to as "infiltration rate". The collected runoff samples were then analyzed for the average steady state sediment yield (hereafter referred to as "sediment yield").

The cone penetrometer was used to record the DTR surrounding the frames before rainfall simulations. Soil moisture was also measured in each runoff frame prior to conducting the rainfall simulations. After rainfall simulation, at least three holes were dug with a trowel to determine the depth to the wetting front, which shows how deeply the water infiltrated within the frame. In 2007, at least nine holes were dug to measure the depth to wetting.

Figure 13 Rainfall simulator and frame.

Figure 14. Rainfall simulation at the no treatment control plot. There was a high percentage of bare ground at this plot.

Statistical Analysis

An analysis of variance test (ANOVA), which compares average values between two or more different groups, was used to resolve differences between plant cover values by treatment type, amendment type, and fertilizer (Biosol) application. If a difference was detected using the ANOVA test, the Tukey test, the student's t-test, and/or the Mann-Whitney test was used to further investigate differences between two sub-groups or sample sets within the larger group. For example, the plant cover differences between compost and tub grinding plots could be tested. The Mann-Whitney test is a non-parametric test that can be applied to data sets with non-normal distributions. Non-normal distributions are common within small data sets. At the Brockway test plots, some of the sample sets only have three replications (n=3). The student's t-test and the Tukey test were applied for data sets with more replications, where non-normal distribution was not a problem.

RESULTS AND DISCUSSION

Rainfall

Treated plots did not produce sediment and therefore infiltrated all the applied water in 2006 and 2007 (Figure 15 and Figure 16). In contrast, the untreated plot had the highest sediment yield and the lowest infiltration rate in 2006. The infiltration rate at the untreated plot was 2 times lower than at the treated plot, 2.3 inches/hour or 60 mm/hr, compared to 4.7 inches/hour (119 mm/hr). The sediment yield at the untreated plot was 407 lbs/acre/inch (180 kg/ha/cm) in 2006.

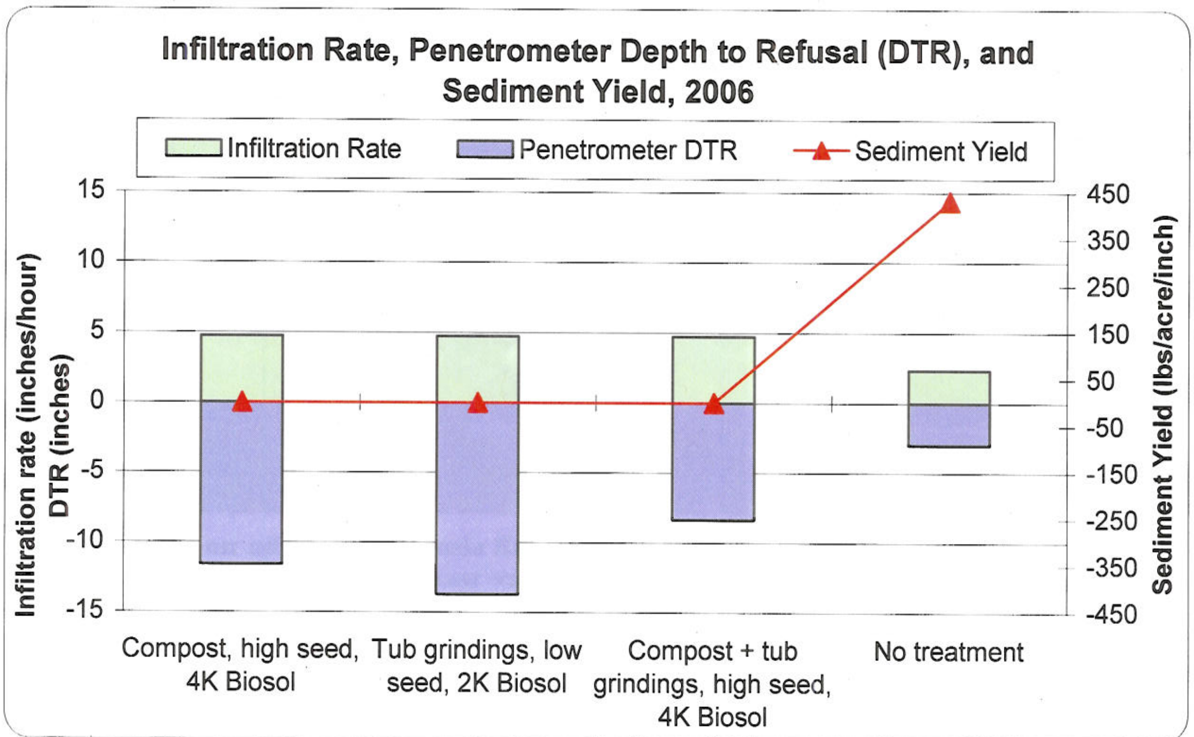

Figure 15. Infiltration Rate, Penetrometer DTR, and Sediment Yield, 2006. Treated plots infiltrated 100% of rainfall and did not produce sediment. The untreated plot exhibited the highest sediment yield, the lowest infiltration rate, and the lowest penetrometer DTR.

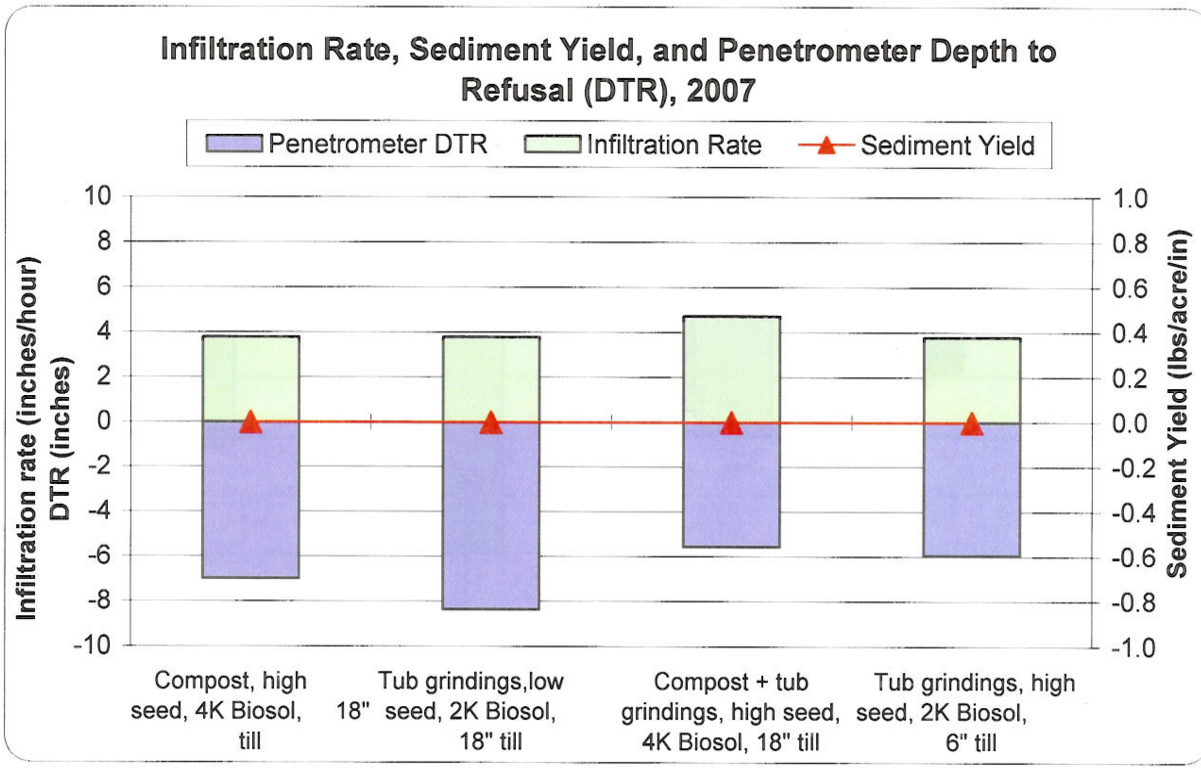

Figure 16. Infiltration Rate, Sediment Yield, and Penetrometer Depth to Refusal (DTR), 2007. Treated plots infiltrated 100% of rainfall and produced no sediment.

<u>Soil Density</u>

In 2006, penetrometer depth to refusals (DTRs) at treated plots were from 63% to 75% deeper than the untreated plot. In 2007, DTRs at the treated plots were 17% to 44% deeper than at the untreated plot (Figure 17). In 2006, treated plots exhibited average DTRs from 8 to 12 inches (20 to 31 cm) compared to 7.1 to 11 inches (18 to 27 cm) in 2007. The average penetrometer depth at the untreated plot was 3 inches (7.6 cm) in 2006 and 6 inches (15 cm) in 2007.

Plots tilled to 18 inches had penetrometer DTRs 42% deeper than the native site in 2006, at least 46% deeper than the plots tilled to 6 inches in both 2006 and 2007 (Figure 17).The plots tilled to 18 inches (46 cm) exhibited average penetrometer depths of 12 inches (30.5 cm) in 2006 and 10.5 inches (26.7 cm) in 2007. The DTR at the native site was 8.4 inches (21.8 cm) in 2006. The plots tilled to 6 inches (15 cm) had an average DTR of 8 inches (20.3 cm) in 2006 and 7.1 inches (18 cm) in 2007.

Though average DTRs remained comparable to native sites, the soil density at the tilled sites increased (penetrometer depth decreased) between 2006 and 2007. The average DTR decreased approximately 11 to 14% at the treated plots, while the penetromter DTRs increased by 50% at the untreated plot from 2006 to 2007 (Figure 17).

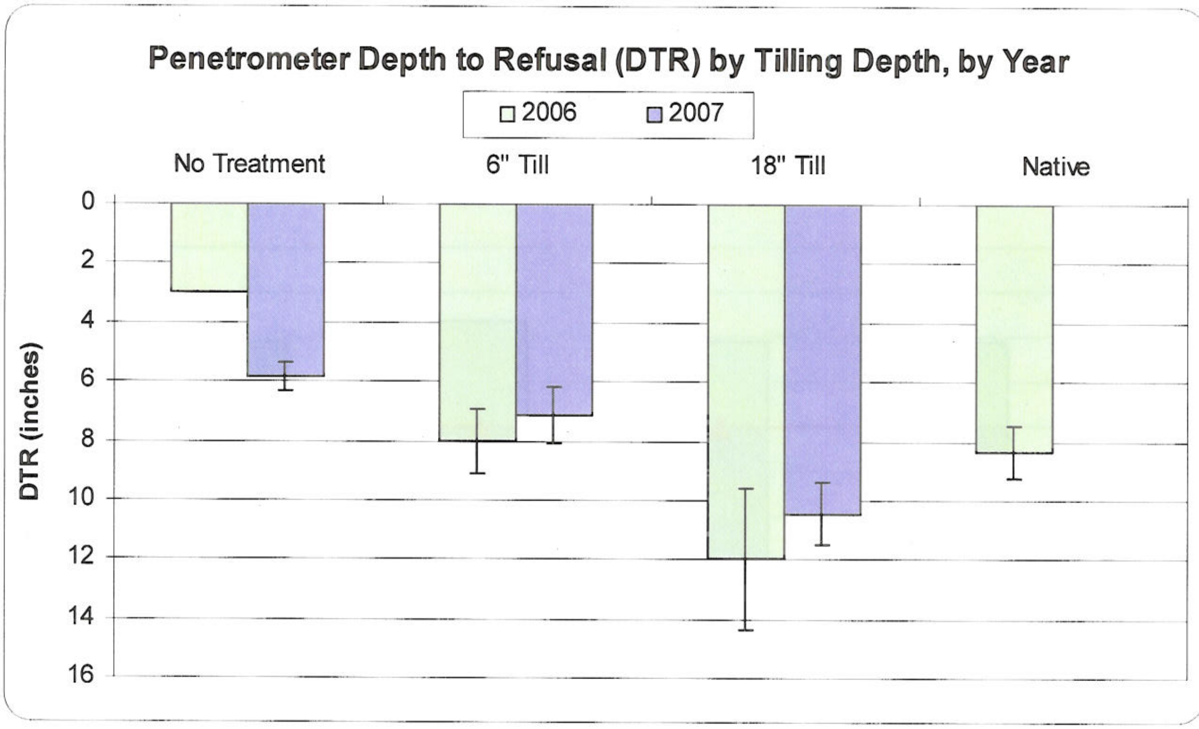

Figure 17. Penetrometer Depth to Refusal (DTR) by Tilling Depth, by Year. The treated plots have deeper average penetrometer depths than the untreated plot. Error bars denote one standard deviation above and below the mean.

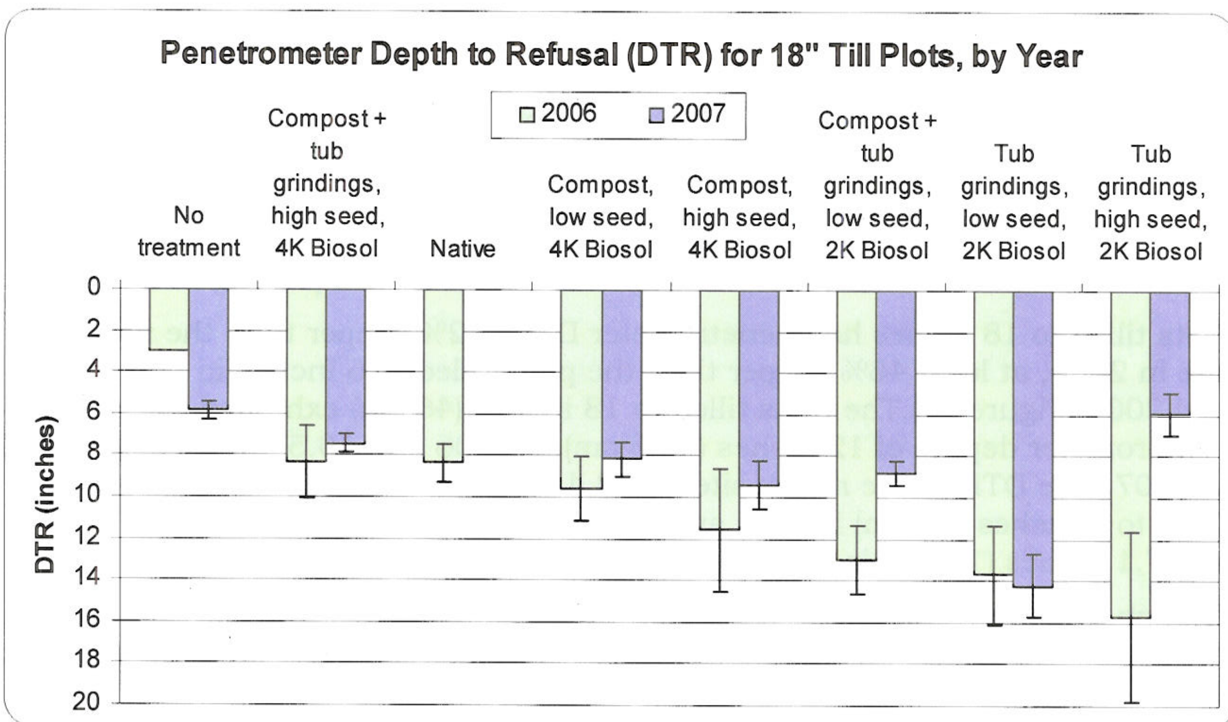

Figure 18. Penetrometer Depth to Refusal (DTR) for 18" Till Plots, by Year. In 2006, plots with tub grindings had the deepest penetrometer readings. Error bars denote one standard deviation above and below the mean.

In 2006, plots amended with tub grindings only had penetrometer depths (DTRs) approximately 15% to 40% deeper than plots tilled with compost alone or compost with tub grindings, according to the Mann-Whitney test ($U_{(4,8)}=26$, $p=0.11$) (Figure 18 and Figure 19).

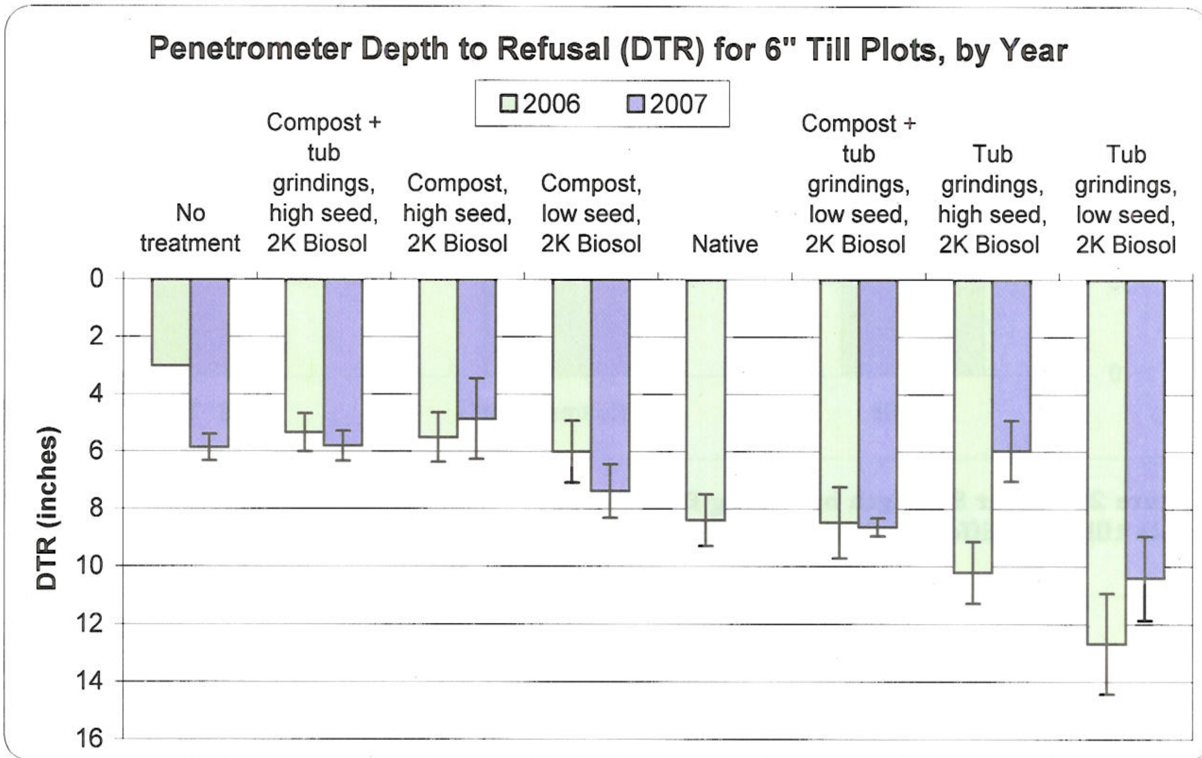

Figure 19. Penetrometer Depth to Refusal (DTR) for 6" Till Plots, by Year. In 2006, plots with tub grindings had the deepest penetrometer depths (DTRs). Error bars denote one standard deviation above and below the mean.

Soil Strength

Soil strength did not vary greatly between tests plots with different tilling depths or amendment types (Figure 20). Soil strength averaged 22.1 kPa in plots tilled to 18 inches (46 cm) and 25.3 kPa at plots tilled to 6 inches (15 cm), while no treatment site without tilling measured an average of 25.2 kPa (Figure 20). Shear stress did vary more than 2% among the different amendment types (Figure 21). The native site measured 31.5 kPa. Soil strength can be derived from several different mechanisms, not all of which are beneficial to the plant and soil ecosystem. The untreated soil most likely derived its strength from greater soil density, while the full treatment plots most likely derived strength from soil structure or deep perennial plant roots.

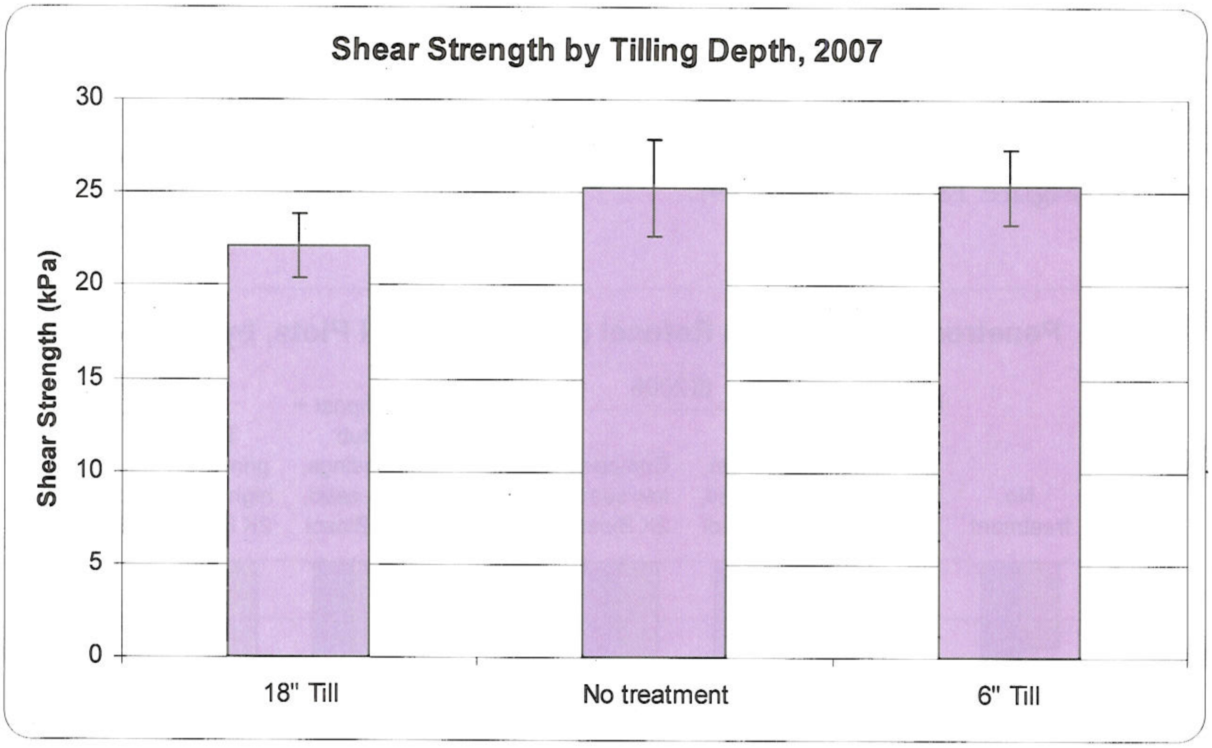

Figure 20. Shear Strength by Tilling Depth, 2007. Shear stress was comparable between plots tilled to different depths and the no treatment plot.

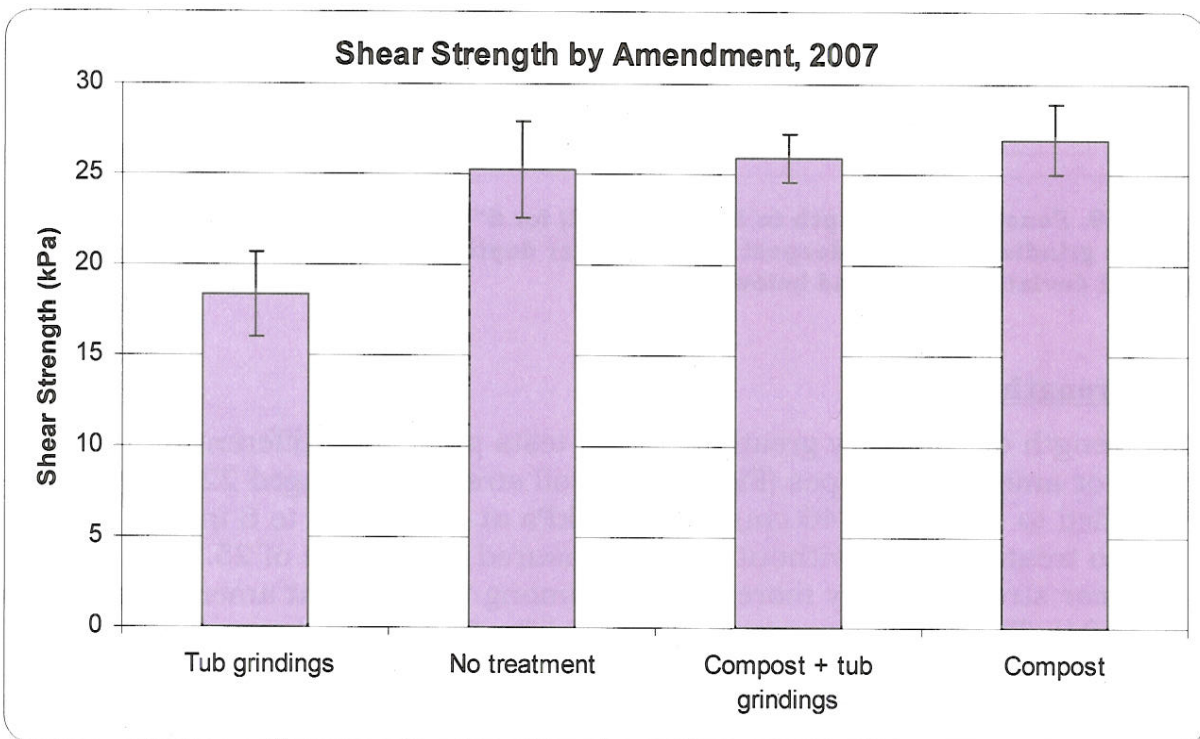

Figure 21. Average Shear Strength by Amendment, 2007. The plot with tub grindings exhibited slightly lower shear strength.

Cover

Mulch Cover

Mulch cover was at least 4 times higher on the treated plots than the untreated plot (Figure 22 and Figure 23). In 2006, average mulch cover on treated plots was 84% to 95%, compared to 5% mulch cover on the untreated plot (Figure 22). In 2007, mulch cover at the treated plots was 82% to 92%, compared to 17% at the untreated plot (Figure 23). The treated plots did not produce any sediment, while the untreated plot had a high sediment yield (Figure 15 and Figure 16). Grismer and Hogan reported that high mulch cover is often associated with sediment reduction on Tahoe soils, thus supporting these findings.[5]

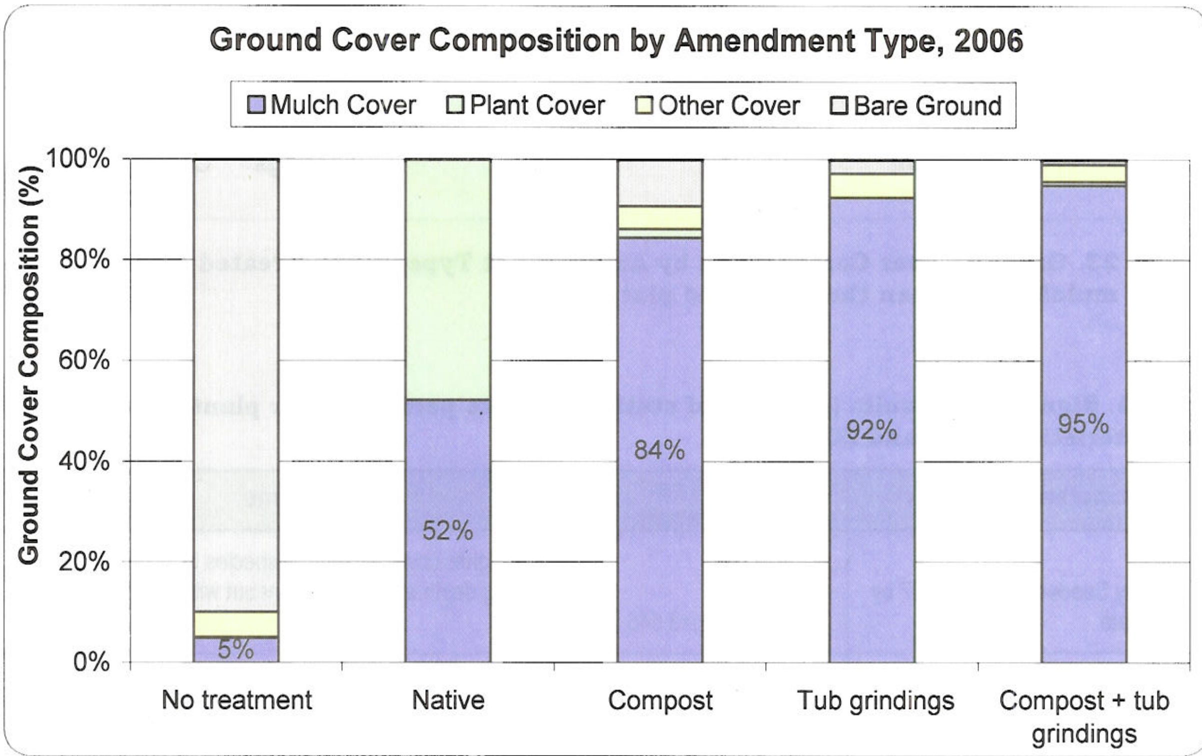

Figure 22. Ground Cover Composition by Amendment Type, 2006. Treated plots had higher mulch cover than the untreated plot. Mulch cover at the native site was low because low lying native plants were present on the ground level.

[5] Grismer, ME, Hogan, MP. 2004. Evaluation of revegetation/mulch erosion control using simulated rainfall in the Lake Tahoe basin: 1. Method Assessment. *Land Degrad. & Develop.* 13:573-578.

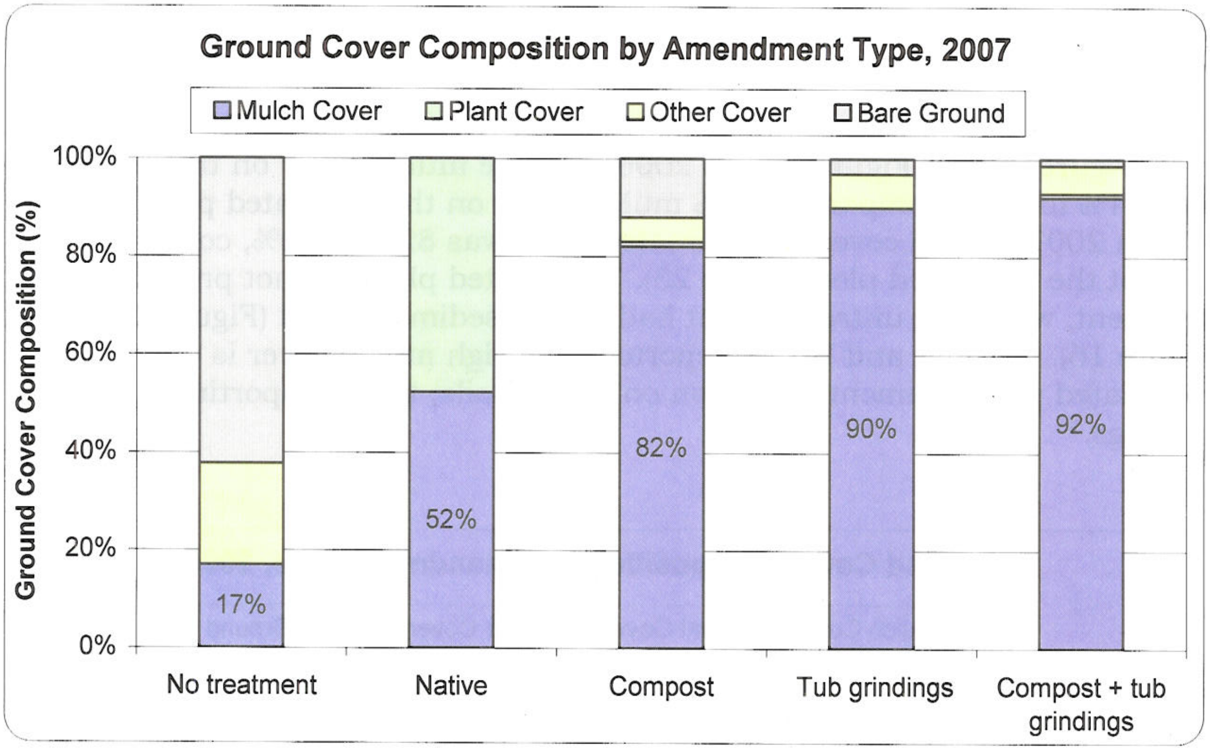

Figure 23. Ground Cover Composition by Amendment Type, 2007. Treated plots had higher mulch cover than the untreated plot.

Table 3. Significant results (p <0.10) of statistical tests performed for plant cover characteristics, 2006 and 2007.

Characteristic/Factor*	Test	Test Statistic	Outcome
Cover by Seeded Species 2007 by Seed Rate	Paired t-test	$T_{(5)}$=3.645	There is higher cover by seeded species in plots with the same tilling depth and amendment but with a higher seed rate.
Annual/Total Plant Cover, 2006 by Amendment Type	ANOVA	$F_{(2,9)}$ = 5.459	Proportion of cover by annual species differs by amendment type
Annual/Total Plant Cover 2006 Compost vs. Tub Grindings	Tukey	q = 4.049	Proportion of cover by annual species is higher on plots with compost versus tub grindings
Annual/Total Plant Cover 2006 Compost and TG vs. Tub Grindings	Tukey	q = 4.045	Proportion of cover by annual species is higher on plots with compost and TG versus tub grindings
Annual/Total Plant Cover, 2007 by Amendment Type	ANOVA	$F_{(2,9)}$ = 26.710	Proportion of cover by annual species differs by amendment type
Annual/Total Plant Cover 2007 Compost vs. Tub Grindings	Tukey	q = 9.583	Proportion of cover by annual species is higher on plots with compost versus tub grindings
Annual/Total Plant Cover 2007	Tukey	q = 8.146	Proportion of cover by annual species is higher on plots with

Characteristic/Factor*	Test	Test Statistic	Outcome
Compost and TG vs. Tub Grindings			compost and TG versus tub grindings
Total Plant Cover 2007 by Amendment Type	ANOVA	$F_{(2,9)} = 11.799$	Total plant cover differs by amendment type
Total Plant Cover 2007 Compost vs. Tub grindings	Tukey	q= 6.068	Total plant cover is higher on plots with compost than plots with tub grindings
Total Plant Cover 2007 Compost and TG vs. Tub grindings	Tukey	q=5.824	Total plant cover is higher on plots with compost and TG than plots with tub grindings
Total Plant Cover 2006 by Amendment Type	ANOVA	F=(2,9) = 7.613	Total plant cover differs by amendment type
Total Plant Cover 2006 Compost vs. Tub grindings	Tukey	q= 4.886	Total plant cover is higher on plots with compost than plots with tub grindings
Total Plant Cover 2006 Compost and TG vs. Tub grindings	Tukey	q=4.664	Total plant cover is higher on plots with compost and TG than plots with tub grindings
* TG = tub grindings			

Plant Cover and Composition

Foliar Plant Cover

In both 2006 and 2007, plots with tub grindings only had the lowest total plant cover (less than 5%, Figure 24, Figure 25, Figure 26, Figure 27). In comparison, plots with compost or the mix of compost and tub grindings had plant cover greater than 30% in 2006 and greater than 45% in 2007.

There was no significant difference in average foliar plant cover between plots tilled to 6 inches and plots tilled to 18 inches in either 2006 or 2007. Biosol rate also did not have an affect on total plant cover.

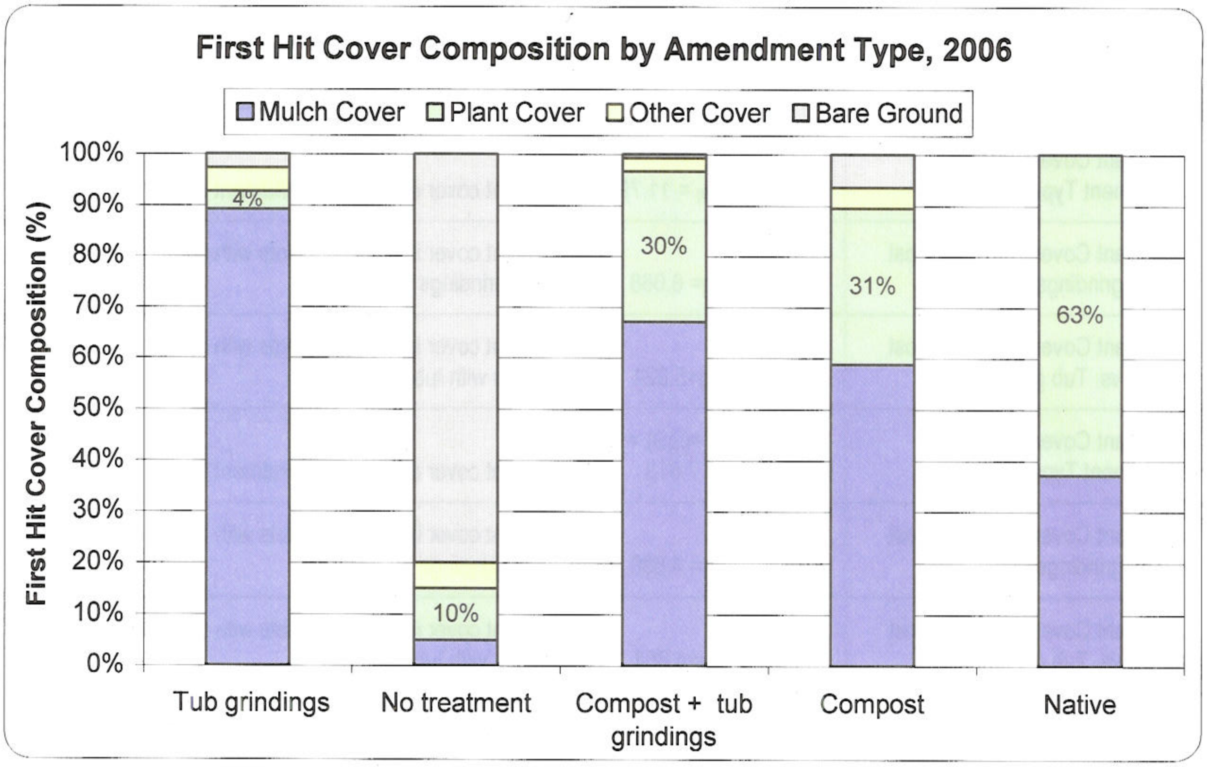

Figure 24. First Hit Cover Composition by Amendment Type, 2006. There is less than 5% plant cover at plots with tub grindings only.

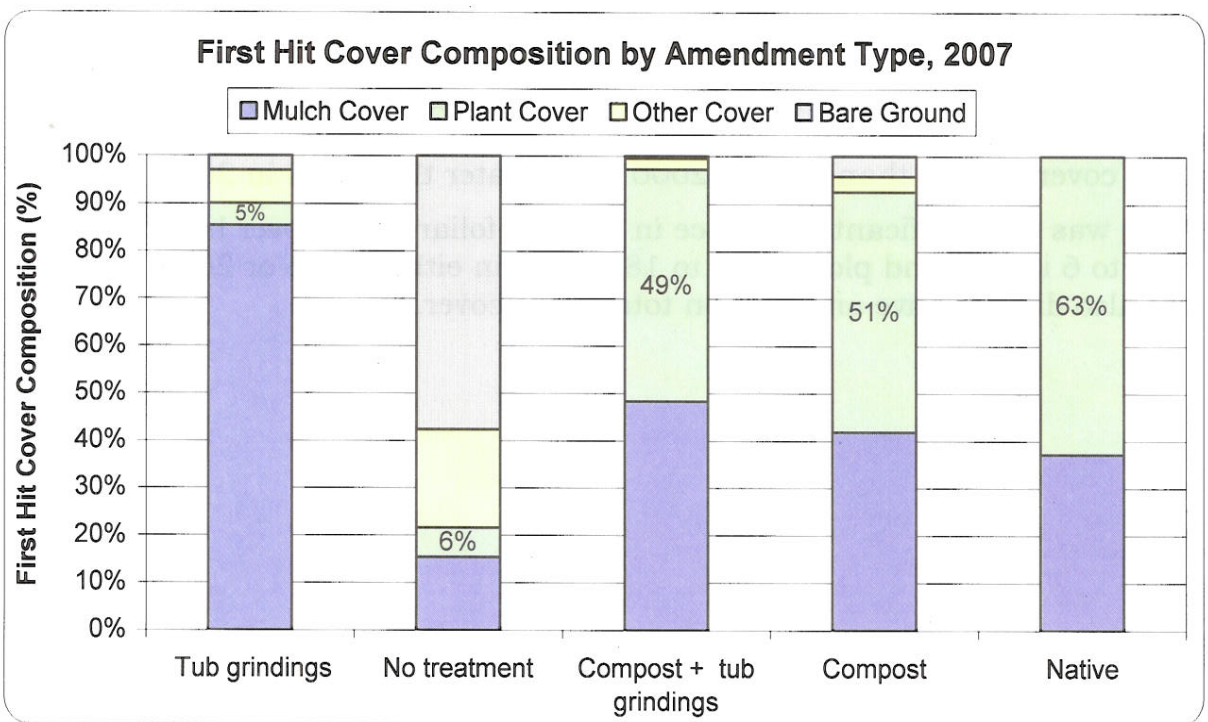

Figure 25. First Hit Cover Composition by Amendment Type, 2007. There is 5%, or less, plant cover at the plots with tub grindings only.

Figure 26. Plot with tub grindings only have no plant cover, but good mulch cover, 2006.

Figure 27. Plot with compost only exhibited high cover by cheatgrass, 2006.

<u>Plant Cover Composition</u>

Cover by annual species, predominantly cheatgrass, was highest on plots with 100% compost or 50% compost. Annual cover was greater than 40% at the plots with compost or a compost and tub grinding mix, compared to plots with tub grindings only, which had less than 2% by annual species (Figure 27, Figure 28 and Figure 29, Figure 30 and Figure 31). Foliar cover by cheatgrass at plots with tub grindings (less than 2%) was 27 times less than at plots with compost (44%) or a combination of compost and tub grindings (40%). The higher available soil nitrogen in plots with compost may produce a favorable environment for the growth of cheatgrass. Tub grindings, which have less available nitrogen, may retard the establishment of cheatgrass, allowing slower growing perennial species to establish.

Biosol rate did not affect annual and perennial plant cover composition in 2006 or 2007. The slight differences in annual and perennial plant cover by tilling depth were not statistically significant because there was overlap in values, as shown by the standard deviation, (Figure 28 and Figure 29).

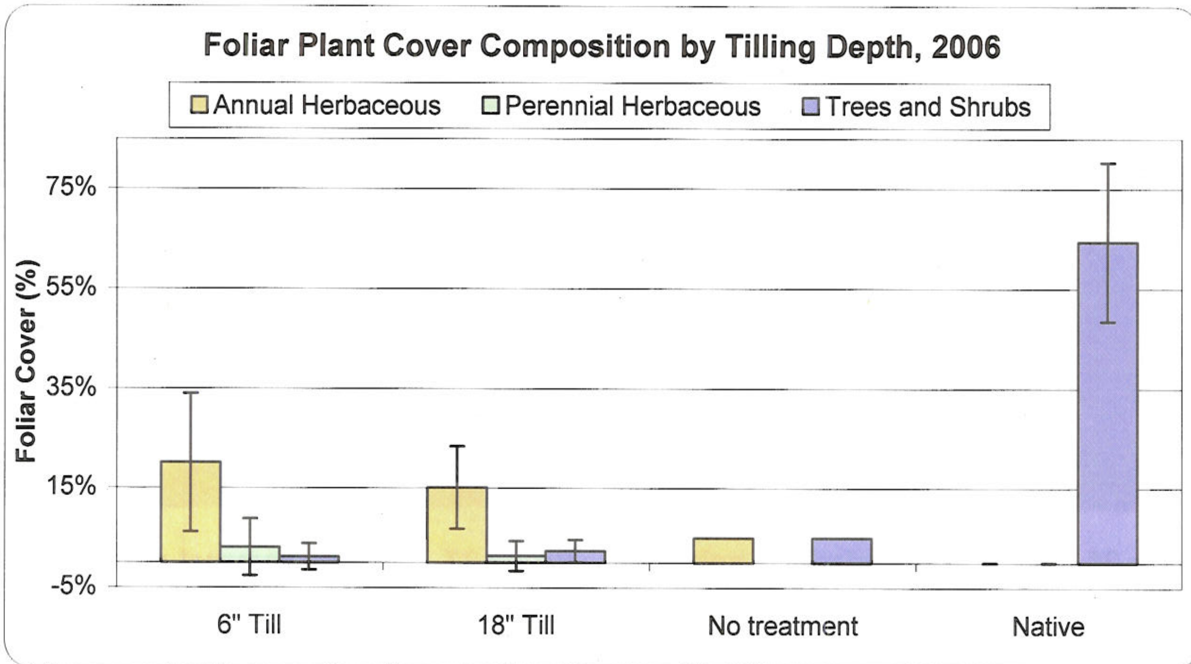

Figure 28. Foliar Plant Cover Composition by Tilling Depth, 2006. There is no statistically significant difference in plant cover between plots tilled 6 or 18 inches deep. Error bars denote one standard deviation above and below the mean. Cover on the no treatment plot was estimated, therefore, a standard deviation could not be calculated.

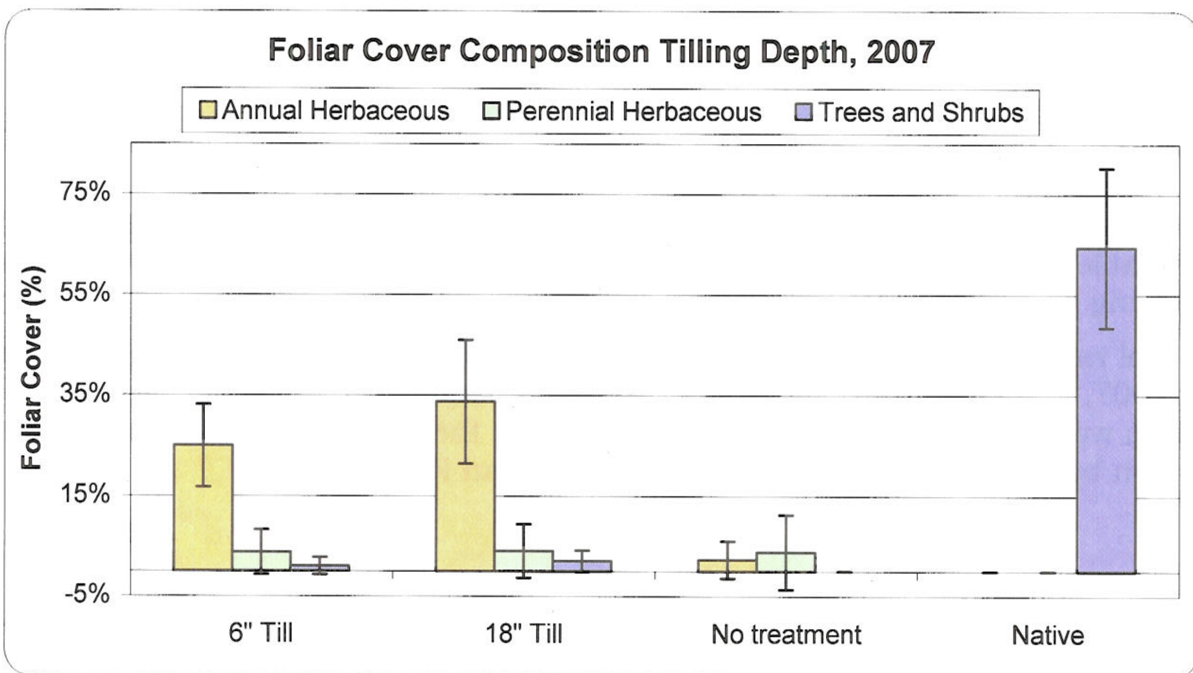

Figure 29. Foliar Plant Cover Composition by Tilling Depth, 2007. There is no statistically significant difference in plant cover between plots tilled 6 or 18 inches deep. Error bars denote one standard deviation above and below the mean.

Cover by seeded species was low on all plots: 2.6% on compost plots, 1.2% on tub grindings plots and 0.4% on plots with compost and tub grindings (Figure 30). Proportionally, cover by seeded species was highest on plots with tub grindings, 25% of total plant cover, as compared to approximately only 5% of total plant cover on plots with compost and less than 1% on plots with compost and tub grindings (Figure 30).

In 2007, there was significantly higher cover by seeded species on plots with the higher seed rate (Table 3). This difference, however, was slight as the average cover by seeded species on the high seed rate plots was only 2% and on the low seed rate plots was only 0.5%. Over time, this difference may become greater and may affect total plant cover.

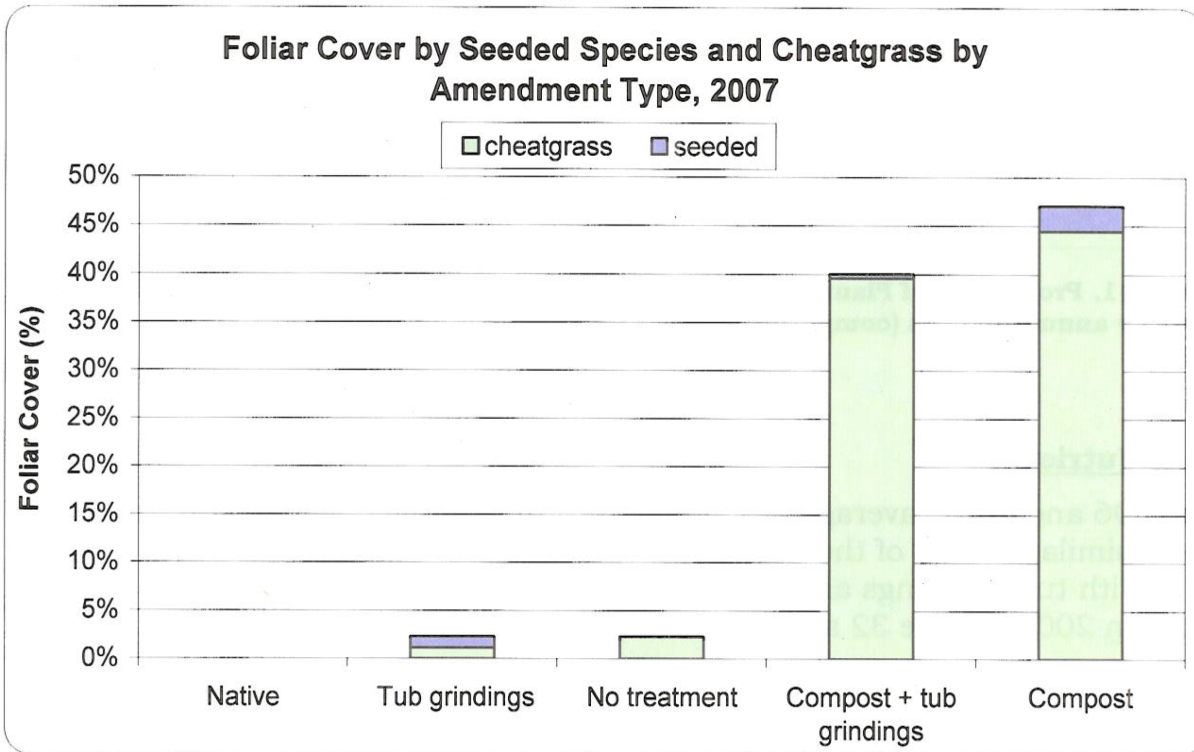

Figure 30. Foliar Cover by Seeded Species and Cheatgrass by Amendment Type, 2007. There was less than 2% cheatgrass on tub grinding plots.

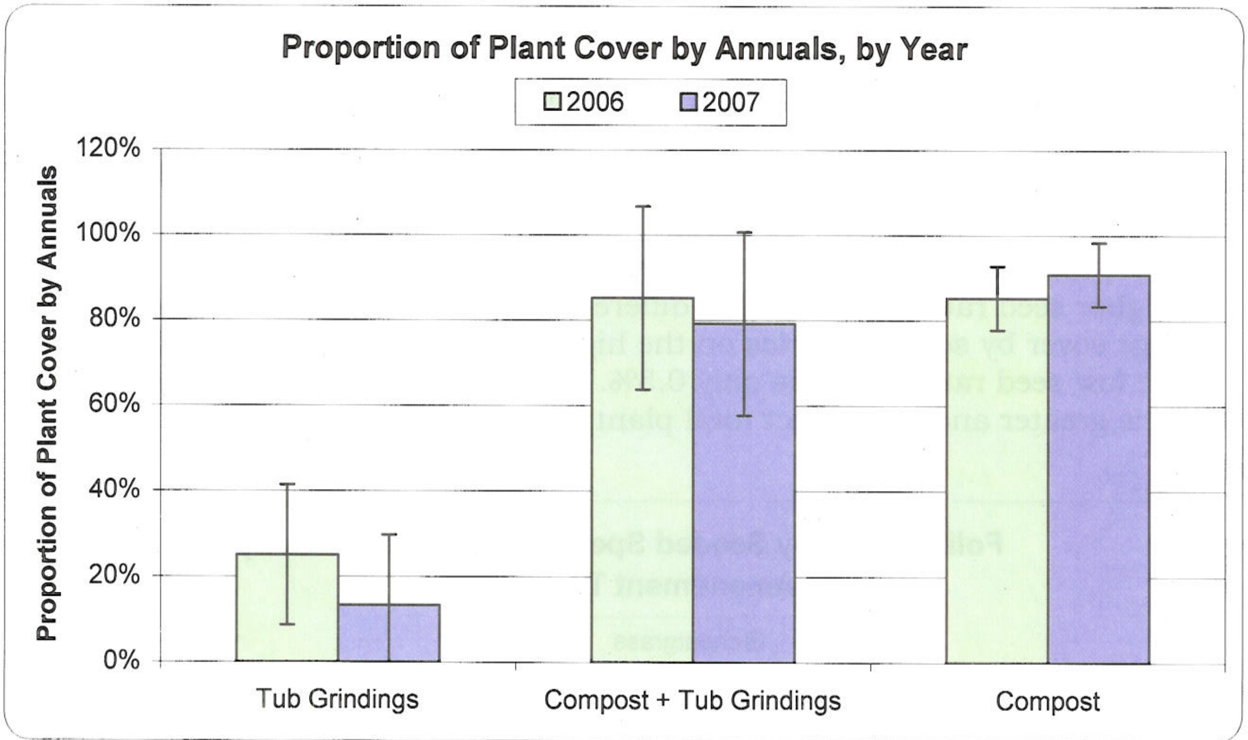

Figure 31. Proportion of Plant Cover by Annuals, by Year. There was proportionally less cover by annual species (composed mostly of cheatgrass) on the tub grinding plots for both years.

Soil Nutrients

In 2006 and 2007, average total Kjeldahl nitrogen (TKN) values at treated plots were similar to that of the native plot (1,638 ppm), with the exception of the plot with tub grindings and the lower Biosol rate, which had a TKN level of 841 ppm in 2007 (Figure 32 and Figure 33).

In 2007, the compost plot with the higher application rate of Biosol had higher TKN levels (2,068 ppm) than compost plots with the lower rate of Biosol (1,647 ppm). The plot with the lower rate of Biosol was only tilled to 6 inches, which may have affected the TKN (Figure 33).

The compost plots were the only plots that maintained TKN values greater than 1,500 ppm for 2006 and 2007 (Figure 32 and Figure 33). TKN in the tub grindings plots ranged from 841 ppm to 1,513 ppm in 2007 while plots with 50% tub grindings and 50% compost had TKN values around 1,000 ppm (Figure 33). The compost plot with the lower Biosol rate had 1,647 ppm of TKN.

In 2006, the organic matter content on the tub grinding plots was greater than 6%, which was closest to the native plot (Figure 32). Organic matter was less than 5% in all other amended plots. In 2007, the percent organic matter was more similar among amendment types, with both tub grindings and compost plots having values greater than 5% (Figure 33).

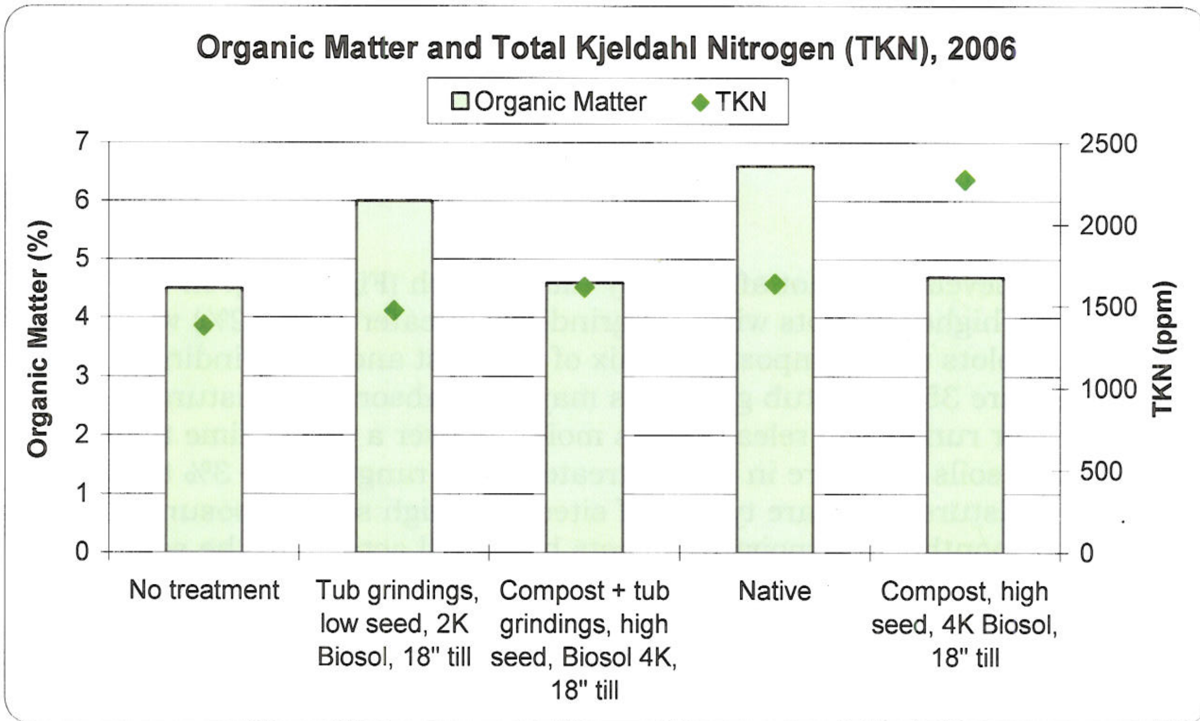

Figure 32. Organic Matter and Total Kjeldahl Nitrogen (TKN), 2006. The highest TKN was observed in the test plot with compost and the highest Biosol rate.

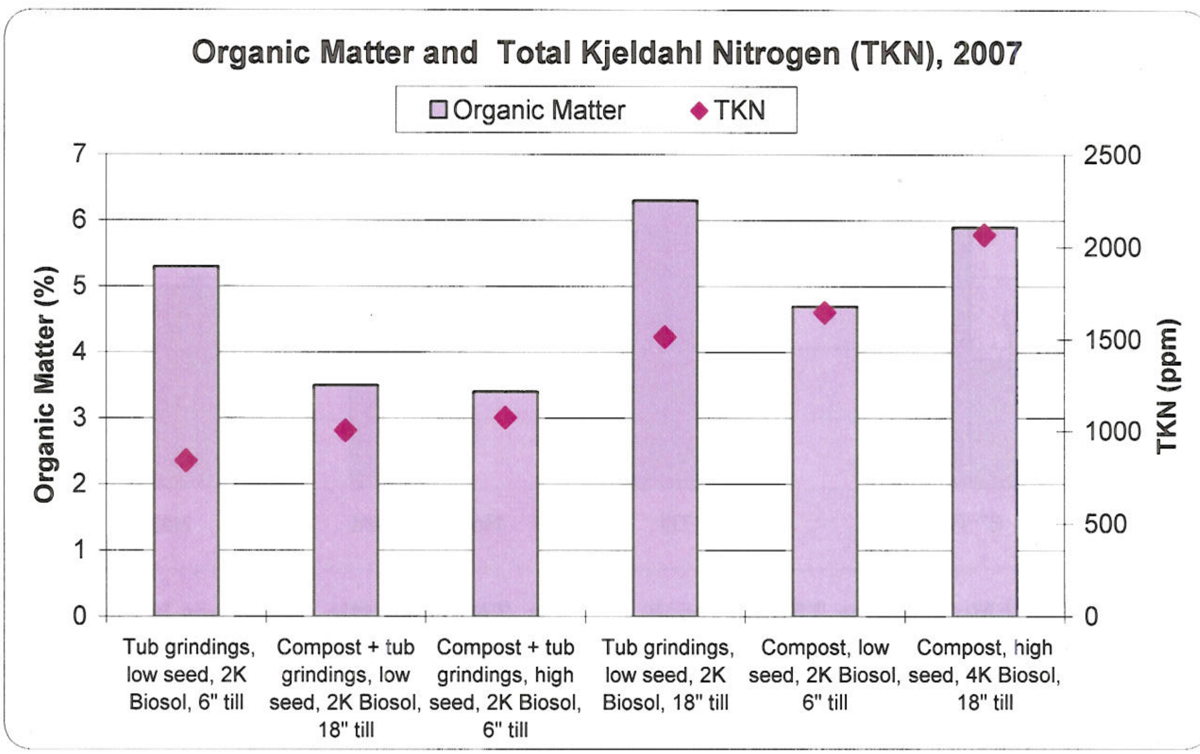

Figure 33. Organic Matter and Total Kjeldahl Nitrogen (TKN), 2007. The highest TKN was observed in the test plot with compost and the highest Biosol rate.

Solar Radiation

The high year-round solar exposure (greater than 90%) resulted in early spring snow melt and higher soil temperatures. This allows for early plant germination, which may favor annual species such as cheatgrass, rather than native bunchgrasses.

Soil Moisture

Soil moisture levels were not affected by tilling depth (Figure 34). In 2007, soil moisture was higher in plots with tub grindings (greater than 12%) when compared to plots with compost or a mix of compost and tub grindings (less than 8% (Figure 35.). The tub grindings may have absorbed moisture from spring rains or runoff and released this moisture over a longer time than compost. The soils moisture in all the treated plots ranged from 3% to 12%. These soil moisture levels are typical of sites with high solar exposure during the summer months. Soil moisture affects biological activity in the soil. This activity is maximized at certain moisture levels with considerable decreases in biological activity above or below those levels. [6, 7]

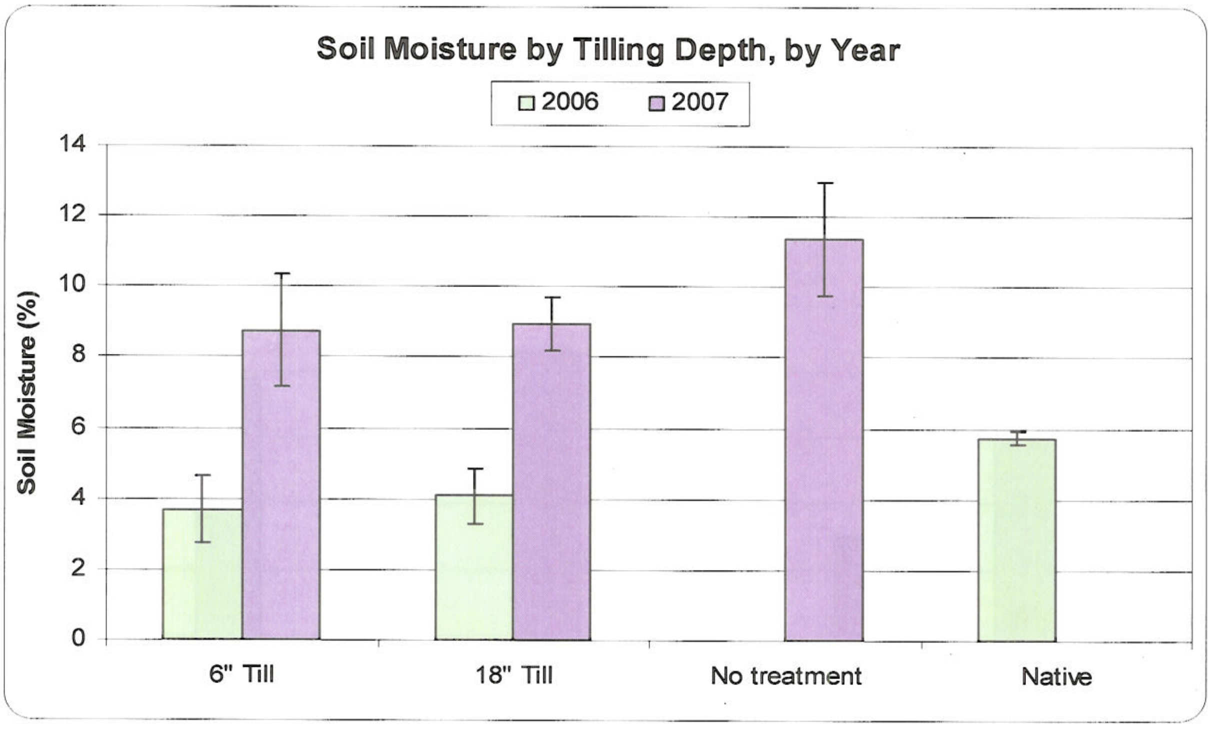

Figure 34. Soil Moisture by Tilling Depth, by Year. There is little difference between tilling depths. Error bars denote one standard deviation above and below the mean.

[6] Paul E. A. and F.E. Clark. 1989. Soil Microbiology and Biochemistry. San Diego: Academic Press

[7] Allen, M.F. 1992. Mycorrhizal Functioning. NY: Chapman and Hall.

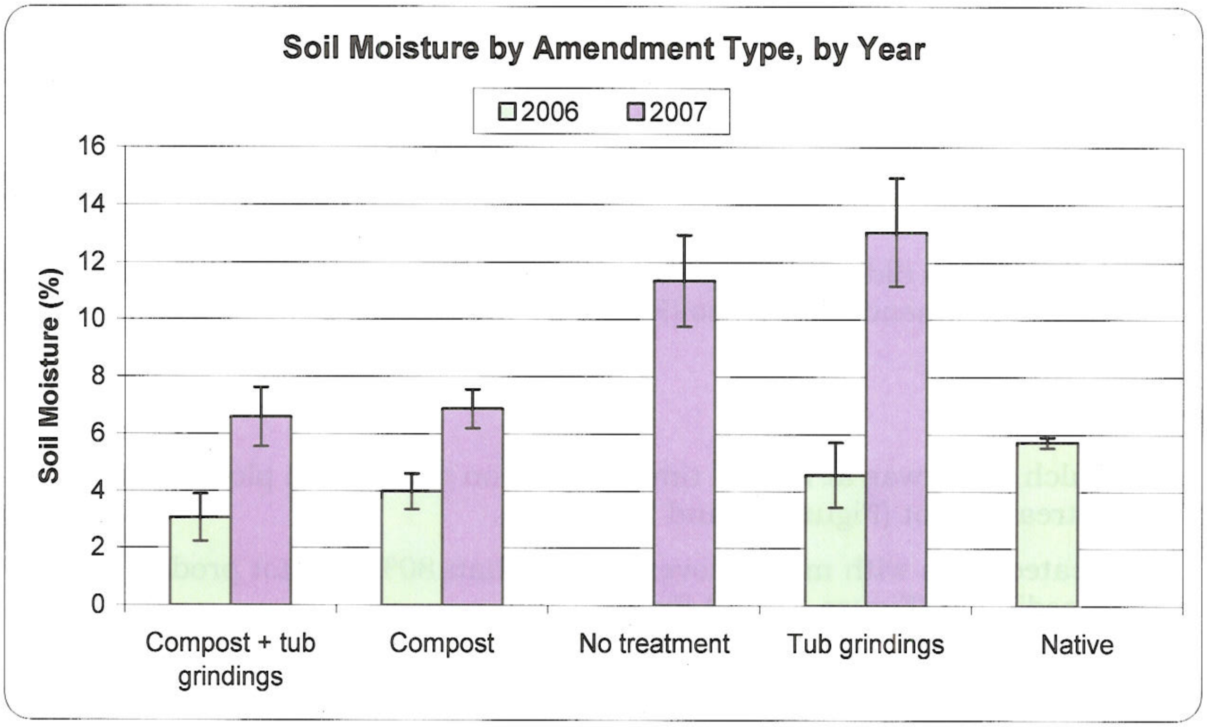

Figure 35. Soil Moisture by Amendment Type, by Year. Plots with tub grindings exhibited significantly higher soil moisture in 2007. Error bars denote one standard deviation above and below the mean.

CONCLUSIONS

Infiltration

- Full treatment produced no sediment and infiltrated all the applied water in 2006 and 2007 (Figure 15 and Figure 16).
- The untreated plot had the highest sediment yield and the lowest infiltration rate in 2006 (Figure 15).

Soil Density

- Penetrometer depths at treated plots were from 17% to 75% deeper than the untreated plot (Figure 17).
- Plots tilled to 18 inches had penetrometer DTRs 42% deeper than the native site in 2006, at least 46% deeper than plots tilled to 6 inches in both 2006 and 2007 (Figure 17).
- In 2006, plots amended with tub grindings alone had penetrometer depths, approximately 15% to 40% deeper than plots with compost alone or compost with tub grindings, (Figure 17, Figure 18 and Figure 19).

- Though average DTRs remained comparable to native sites, tilled sites exhibited increased soil density from 2006 to 2007. The average DTR decreased approximately 11 to 14% at the treated plots, while the. penetrometer DTRs increased by 50% at the untreated plot from 2006 to 2007 (Figure 17).

Soil Strength

- Soil strength did not vary greatly between tests plots with different tilling depths or amendment types (Figure 20 and Figure 21).

Mulch Cover

- Mulch cover was at least 4 times higher on the treated plots than on the untreated plot (Figure 22 and Figure 23).
- Treated plots with mulch cover greater than 80% did not produce runoff or sediment (Figure 15 and Figure 16).

Plant Cover and Composition

- There was no significant difference in average foliar plant cover between plots tilled to 6 inches and plots tilled to 18 inches in either 2006 or 2007 (Figure 22 and Figure 23).
- Biosol rate did not have an affect on total plant cover or annual and perennial plant composition.
- In both 2006 and 2007, plots with tub grindings only had the lowest total plant cover (less than 5%). Plots with compost or the mix of compost and tub grindings had greater than 30% plant cover in 2006 and greater than 45% in 2007 (Figure 22 and Figure 23).
- Cover by annual species, predominantly cheatgrass, was highest on plots with 100% compost or 50% compost. Cover by annuals was greater than 40% at the plots with compost or compost and tub grindings, compared to plots with tub grindings only, which had annual plant cover of less than 2% (Figure 27, Figure 28 and Figure 29).
- Foliar cover by cheatgrass at plots with tub grindings (less than 2%) was 27 times less than at the plots with compost (44%) or a combination of compost and tub grindings (40%).
- Annuals composed greater than 75% of total plant cover at the 100% and the 50% compost plots (Figure 27, Figure 28, Figure 29 and Table 3).

- Cover by seeded species was low on all plots: 2.6% on compost plots, 1.2% on tub grindings plots, and 0.4% on plots with compost and tub grindings (Figure 30).
- In 2007, there was significantly higher cover by seeded species on plots with higher seed rates, but this difference was small (0.5%) (Table 3).

Soil Nutrients

- In 2006, the organic matter content at the tub grinding plots was greater than 6%, which was closest to the native plot (Figure 32). Organic matter was less than 5% in all other amended plots.
- The compost plots were the only plots that maintained TKN values greater than 1,500 ppm from 2006 and 2007 (Figure 32 and Figure 33).
- In 2007, the compost plots with the higher application rate of Biosol had higher TKN levels (2,068 ppm) than the compost plot with the lower rate of Biosol (1,647 ppm).
- In 2006 an 2007, average total Kjeldahl nitrogen (TKN) values at treated plots were similar to that of the native plot (1,638 ppm), with the exception of the plot with tub grindings and the lower Biosol rate, which had a TKN level of 841 ppm in 2007 (Figure 32 and Figure 33).

Solar Radiation

- The high year-round solar exposure (greater than 90%) resulted in early spring snowmelt and higher soil temperatures. This allows for early plant germination, which may favor annual species such as cheatgrass, rather than native bunchgrasses.

Soil Moisture

- Soil moisture levels were not affected by tilling depth (Figure 34).
- In 2007, soil moisture was higher in plots with tub grindings (greater than 12%) when compared to plots with compost or a mix of compost and tub grindings (less than 8%, Figure 35.).

RECOMMENDATIONS

These recommendations are for 2:1 cut slopes, with year-round solar exposure of greater than 90%, at an elevation of 6,900 feet (2,125 m), on volcanic parent material soil with an existing seed bank of cheatgrass seeds:

Tilling: 18 inches

Amendment: 4 inches of compost with 25% fines, 75% coarse overs

Biosol: 1,784 lbs/acre (2,000 kg/ha)

Seed: 285 lbs/acre (319 kg/ha) seed with the following composition:

50% squirreltail
15% mountain brome
25% Western needlegrass
10% native forbs

Mulch: 2 to 3 inches of pine needle mulch applied to greater than 99% cover

Full Treatment versus No treatment

All full treatment plots performed better in terms of erosion control capacity than the no treatment plot. Treatment plots exhibited:

- no sediment production while the untreated plots produced 407 lbs/acre/inch or 180 kg/ha/cm
- infiltration rates that were 2 times higher when compared to the untreated plot (4.7 in/hr or 119 mm/hr compared to 2.3 in/hr or 60 mm/hr)
- penetrometer DTRs that were 2.3 to 4 times deeper than at the no treatment plot (DTRs ranged from 7 to 12 inches for treatment plots and were less than 3 inches as the no treatment plot)
- mulch cover that was 5 to 19 times greater than at the no treatment plot, which had 5 to 17% cover by mulch

Tilling to 18 inches versus Tilling to 6 inches

Tilling the soil to a depth of 18 inches (46 cm) is recommended over tilling to 6 inches (15.2 cm) for the following reasons. Plots tilled to 18 inches exhibited:

- no sediment production (there was also no sediment production at the 6 inch till plots)
- average penetrometer depths that were 1.5 times deeper than at the 6 inch tilling plots (18 inch till average DTR in 2007: 10.5 inches; 2006: 12 inches; 6 inch till average DTR in 2006: 8 inches; 2007: 7.1 inches)
- similarly high infiltration rates (4.72 inches/hr) to the 6 inch till plots

- similar soil strength to the 6 inch till plots (22.1 to 25.3 kPa)

Amendment Type and Rate (Compost 4" versus Tub grindings 4" versus 50% Compost/50% Tub grindings 4")

Four inches of tub grindings are recommended for the following reasons. Plots with 4" of tub grindings exhibited:

- penetrometer DTRs that were 15 to 40% deeper than DTRs at plots with compost or compost and tub grindings
- foliar cover by cheatgrass (less than 2%) that was 27 times less than at the plots with compost (44%) or a combination of compost and tub grindings (40%)
- a higher proportion of perennial species in both 2006 and 2007. In 2007, 77% of plant cover was by perennial species on tub grinding plots, which was more than 7 times higher than at the compost plots and 3.5 times higher than the plots with compost and tub grindings.
- similar percent organic matter to plots with compost or compost and tub grindings (5% to 6%)

Biosol Rate

Apply Biosol at a rate of 1,784 lbs/acre (2,000 kg/ha) for the following reason. Plots with the lower Biosol rate (1,784 lbs/acre) exhibited:

- the same plant cover and composition as plots with the higher Biosol rate

Seed Rate

Apply seed at a rate of 285 lbs/acre (320 kg/ha) with the following composition:

50% squirreltail
15% mountain brome
25% Western needlegrass
10% native forbs

for the following reasons:

- Plots with the higher seed rate had 4 times higher cover by perennial species, 2%, compared 0.5% with the lower seed rate.

Mulch

Apply pine needle mulch to a depth of 2 to 3 inches and greater than 99% cover for the following reasons. Mulch applied to this depth resulted in:

- no sediment production
- consistent, high ground cover by mulch over two years, with 90% cover or greater at most plots where mulch was applied
- mulch cover that was 5 to 19 times greater than at the no treatment plot

Appendix A

Brockway Summit Test Plots Species List, 2006. T = trace amounts of cover

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Invasive/ Noxious	Ocular Cover (%)												
							Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12	Native
Forb	Brassicaceae	Capsella bursa-pastoris	sheperd's purse	Annual	Alien	Invasive								T					
Forb	Brassicaceae	Descurainia sophia	herb Sophia	Annual	Alien	Invasive	< 5		T						T				
Forb	Geraniaceae	Erodium cicutarium	red stem storksbill	Annual	Alien														
Forb	Asteraceae	Lactuca serriola	devil's lettuce	Annual	Alien						T			T					
Forb	Polygonaceae	Polygonum douglasii	Douglas knotweed	Annual	Native		T												
Forb	Brassicaceae	Sisymbrium altissimum	tumble mustard	Annual	Alien		< 5			T	T	5 - 10		T			20		
Forb	Scrophulariaceae	Verbascum thapsis	mullen	Annual	Native	Invasive									T		T		
Forb	Brassicaceae	Lepidium campestre	English pepperweed	Annual	Alien						T		T	T	T				
Forb	Polemoniaceae	Phlox gracilis	slender phlox	Annual	Native						T								
Forb	Asteraceae	Achillea millefolium	yarrow	Perennial	Native		T		T		T								
Forb	Asteraceae	Antennaria rosea	pussy toes	Perennial	Native												5 - 10		
Forb	Polygonaceae	Eriogonum nudum	nude buckwheat	Perennial	Native						< 5		T						
Forb	Polygonaceae	Eriogonum umbellatum	sulfur flower	Perennial	Native		T		T		< 5	T	T	T			T		
Forb	Onagraceae	Gayophytum diffusum	prarie smoke	Perennial	Native		< 5	T	< 5	< 10	20	T	< 5	T	5 - 10	T	< 5	T	
Forb	Fabaceae	Lotus purshianus	Spanish lotus	Perennial	Native						T	T	T						
Forb	Fabaceae	Lupinus argenteus	silver lupine	Perennial	Native		T	T	T		T	T							
Forb	Fabaceae	Lupinus lepidus (culbertsonii)	Culberton's lupine	Perennial	Native											T			
Forb	Onagraceae	Oenethera sp.	evening primrose	Perennial	Native		T						T						
Forb	Hydrophyllaceae	Phacelia hastata	silverleaf phacelia	Perennial	Native		T										T		
Graminoid	Poaceae	Bromus tectorum	cheatgrass	Annual	Alien	Invasive	30 - 40		30 - 40	40	25	25	50 - 60	80	30	< 5	25	T	
Graminoid	Poaceae	Hordeum vulgare	barley	Annual	Alien		5			T		T	T						
Graminoid	Poaceae	Agropyron intermedium	intermediate wheatgrass	Perennial	Alien										5				
Graminoid	Poaceae	Bromus carinatus	mountain brome	Perennial	Native			< 5	T	T	< 5	T	< 5	< 5		< 5	< 5	T	
Graminoid	Poaceae	Deschampsia elongata	elongated hairgrass	Perennial	Native						T								
Graminoid	Poaceae	Elymus elymoides	squirrel's tail grass	Perennial	Native		< 5		< 5						T	T		T	
Graminoid	Poaceae	Elymus glaucus	blue wildrye	Perennial	Native		5		T		< 5			T	T	T			
Shrub	Ericaceae	Arctostaphylos patula	Greenleaf Manzinita	Perennial	Native														D
Shrub	Rhamnaceae	Ceanothus prostratus	Squaw Carpet	Perennial	Native														D
Shrub	Fagaceae	Quercus vacinifolia	huckleberry leaf oak	Perennial	Native														D
Tree	Pinaceae	Pinus jefferyi	Jeffrey pine	Perennial	Native								T	5 - 10			< 5		

Species list for the Brockway Summit test plots, 2007 T = trace amounts of cover.

Lifeform	Family	Scientific name	Common name	Annual/ Perennial	Native/ Alien	Invasive/ Noxious	% in seed mix	Ocular Cover (%) Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11	Plot 12	Control
Forb	Asteraceae	Achillea millefolium	yarrow	Perennial	Native		4.82%			T										
Forb	Asteraceae	Antennaria rosea	pussy toes	Perennial	Native													<5		
Forb	Brassicaceae	Arabis holboellii	Holboel's rockcress	Perennial	Native						T									
Forb	Brassicaceae	Capsella bursa-pastoris	sheperd's purse	Annual	Alien	Invasive														
Forb	Brassicaceae	Descurainia sophia	herb Sophia	Annual	Alien	Invasive		T										T		
Forb	Polygonaceae	Eriogonum nudum	nude buckwheat	Perennial	Native		4.82%		T		<5	5-10	<5	<5		<5				
Forb	Polygonaceae	Eriogonum umbellatum	sulfur flower	Perennial	Native			5-10		<5	5	5-10	5-10	5-10	5	5	T	<5	<5	
Forb	Geraniaceae	Erodium cicutarium	red stem storksbill	Annual	Alien									T						
Forb	Onagraceae	Gayophytum diffusum	prarie smoke	Perennial	Native				T	<5	T		T			T				T
Forb	Brassicaceae	Isatis tinctoria	dyer's woad	Annual	Alien	Noxious		5-10			T			<5						
Forb	Fabaceae	Lotus purshianus	Spanish lotus	Perennial	Native		7.24%													
Forb	Fabaceae	Lupinus argenteus	silver lupine	Perennial	Native		4.82%									T	T			
Forb	Fabaceae	Lupinus lepidus (culbertsonii)	Culberton's lupine	Perennial	Native															
Forb	Fabaceae	Lupinus fulcratus	green stipuled lupine	Perennial	Native		4.82%													
Forb	Hydrophyllaceae	Phacelia hastata	silverleaf phacelia	Perennial	Native			T	T											
Forb	Brassicaceae	Sisymbrium altissimum	tumble mustard	Annual	Alien									T				<5		
Forb	Scrophulariaceae	Verbascum thapsis	mullen	Annual	Native	Invasive											T			
Graminoid	Poaceae	Agropyron intermedium /Elytrigia intermedia ssp. intermedia	intermediate wheatgrass	Perennial	Alien			T					T		5	5				
Graminoid	Poaceae	Bromus carinatus	mountain brome	Perennial	Native		24.12%	T	T	T	T			T			<5			
Graminoid	Poaceae	Bromus tectorum	cheatgrass	Annual	Alien	Invasive		55 - 60	T	40-45	65	50-60	T	70	70	30	<5	80	T	T
Graminoid	Poaceae	Dactylis glomerata	orchard grass	Perennial	Alien	Invasive						T								
Graminoid	Poaceae	Deschampsia elongata	elongated hairgrass	Perennial	Native															
Graminoid	Poaceae	Elymus elymoides	squirrel's tail grass	Perennial	Native		4.82%						T			T	T			
Graminoid	Poaceae	Elymus glaucus	blue wildrye	Perennial	Native		24.12%	T				T								
Shrub	Rosaceae	Prunus emarginata	bitter cherry	Perennial	Native				T											T
Shrub	Rosaceae	Purshia tridentata	antelope bitterbrush	Perennial	Native		4.82%													
Tree	Pinaceae	Pinus jeffreyi	Jeffrey pine	Perennial	Native									T	10			5	5-10	